Description

ON ENGINE TRIM FOR FUEL INJECTORS

Technical Field

[01] This invention relates generally to a method and apparatus for trimming fuel injectors in an engine and, more particularly, to a method and apparatus for trimming fuel injectors based on changes in engine speed during cutout of injection events.

Background

[02] Due to variations in individual fuel injectors and the need for consistent performance among all injectors used in an engine, various techniques have been employed in attempts to match performance characteristics of injectors for use as a set in an engine. For example, manufacturing processes must observe strict tolerances to help achieve uniformity of injector specifications. In spite of this, performance differences still exist, which may be addressed by electronic trimming (e-trim) of the injectors on a test bench, and subsequent matching of injector sets for use in an engine.

[03] The above techniques, however, can only be effective to a certain extent. Since manufacturing strategies and test bench e-trim processes are conducted under restricted conditions, the reality of use in an engine under a wide variety of operating conditions reveals shortcomings of injector-to-injector performance that are not evident otherwise. In particular, injector performance during low idle conditions, i.e., when very small fuel quantities are being demanded of the injectors, may not be as optimal as performance under operating conditions which more closely resemble test bench conditions.

[04] In addition, conditions related to the operation of the engine itself, such as changing temperature conditions (both with respect to time and location on the engine) and low pressure dynamics (particularly during low idle) contribute to variations in injector performance characteristics.

[05] Attempts have been made in the past to trim injectors after installation on an engine. Typically, these methods involve cutting out operation of one injector at a time and monitoring changes in fuel delivery to the remaining injectors. The changes in fuel delivery are analyzed to determine trim requirements for each injector, typically in the form of varying injection duration. It has been found, however, that the changes in fuel delivery may not offer enough resolution for analysis, particularly during low idle conditions when the amount of fuel demanded is very small. The problem is compounded, moreover, when engine operations involves delivery of multiple shots of fuel, such as a split injection mode, thus making individual fuel deliveries much smaller.

[06] An alternative to measuring changes in fuel delivery during cutout testing is to monitor changes in engine speed, a parameter that may offer more resolution for incremental changes. For example, in U.S. Patent No. 5,113,830, Haines discloses a control system which, under certain operating conditions, monitors changes in engine speed as individual injectors are disabled. Haines, however, specifically limits this form of testing to operating conditions in which no speed governing takes place. Therefore, testing cannot be conducted, for example, at low idle speeds, during which the system of Haines is in a "two speed governing mode". Furthermore, Haines conducts testing by disabling injectors completely and does not perform tests in which only injector events, such as particular shots of multi-shot injections, are halted.

[07] The present invention is directed to overcoming one or more of the problems as set forth above.

Summary of the Invention

[08] In one aspect of the present invention a method for trimming a fuel injector located on an engine is disclosed. The method includes the steps of modifying an engine speed control, interrupting at least one injection event, monitoring a change associated with an engine speed, and responsively trimming the injector.

[09] In another aspect of the present invention an apparatus for trimming a fuel injector located on an engine is disclosed. The apparatus includes an engine speed control device, an engine speed sensor, and a controller for modifying an engine speed control of the engine speed control device, interrupting at least one injection event, monitoring a change in engine speed, and responsively trimming the injector.

Brief Description of the Drawings

[10] Fig. 1 is a block diagram illustrating a preferred embodiment of the present invention;

[11] Fig. 2 is an illustrative plot of multiple injection events as may be used in the present invention;

[12] Fig. 3 is a flow diagram depicting a preferred method of the present invention; and

[13] Fig. 4 is a control diagram of an exemplary controller suited for use in the present invention.

Detailed Description

[14] Referring to the drawings and the accompanying claims, a method and apparatus 100 for trimming a fuel injector 104 located on an engine 102 is disclosed.

[15] Referring to Fig. 1 in particular, an engine 102 is shown, including a plurality of fuel injectors 104. The engine 102 may be a compression ignition internal combustion engine using a fuel such as diesel. However, other types of

engines, for example spark ignited, may be used with the present invention as well.

[16] A typical engine for this application would include one or more cylinders (not shown) for combustion, and would have a fuel injector 104 corresponding to each cylinder. For example, as shown in Fig. 1, the engine 102 has n number of fuel injectors 104, and thus would be expected to have n number of cylinders. However, the present invention may also apply to an engine having a differing number of fuel injectors than cylinders, for example multiple fuel injectors per cylinder and such.

[17] The engine 102 may include means 106 for monitoring an engine speed change, more generally referred to as means 106 for monitoring engine speed. Preferably, the means 106 for monitoring engine speed includes an engine speed sensor 108, for example of a type well known in the art.

[18] A controller 114, among other functions, may receive a signal from the engine speed sensor 108, and responsively determine engine speed. The controller 114, in accordance with the present invention, may also receive the signal from the engine speed sensor 108 and responsively determine a change in engine speed, referred to hereinafter as Δ speed.

[19] The controller 114 may also include means 110 for modifying an engine speed control. The means 110 for modifying an engine speed control may include an engine speed control device 112, for example an engine speed governor. The engine speed control device 112 may be software based and located as part of the controller 114 as shown, or may be a separate software based control unit. Alternatively, the engine speed control device 112 may be non-software based, such as for example a mechanical speed governor.

[20] An engine speed control device 112 suited for use with the present invention may include a proportional-integral (PI) controller, as is well known in the art. For example, Fig. 4 illustrates an exemplary PI controller 402 which may

be used with the present invention. It is noted, however, that various other types of controllers may be used, for example PID controllers and such.

[21] The PI controller 402 of Fig. 4 includes a forward PI module 404 which may receive a signal indicative of a comparison of a desired engine speed and an actual engine speed, i.e., an engine speed error term, such as may be produced at summing junction 408. The PI controller 402 also includes a feedback conditioning module 406 which receives a signal representative of an actual engine speed, processes the signal, and delivers the processed signal to summing junction 408. The forward PI module 404 may process the engine speed error signal from summing junction 408 and calculate a desired fuel quantity, preferably to maintain the actual engine speed equivalent to the desired engine speed. It is noted that the forward PI module 404 may contain gain terms for each of the proportional and the integral portions of the module. These gain terms may be controlled, as described below. It is also noted that the PI controller 402 may include additional modules to perform additional signal processing, and one or the other of the forward PI and feedback conditioning modules 404,406 may not be included.

[22] Referring still to Fig. 1, the controller 114 may include means 116 for interrupting an injection event. An injection event may refer to an injection of a total amount of fuel by an injector 104, or may refer to an injection of a portion of a total amount of fuel, for example a pilot or a main injection. Thus, for example one injection event may be a pilot injection and another injection event may be a main injection.

[23] Referring to Fig. 2, a plot 202 indicating a series of injection events is shown. Two injection events, a pilot injection event 208 and a main injection event 210 are indicated. The X-axis 204 of the plot 202 may be indicative of time, crank angle, or some other suitable variable. The Y-axis 206 may indicate magnitude of current, fuel, and the like. The plot 202 is shown displaying pilot and main injection events 208,210 having the same duration; that

is, the pilot injection event 208 has a duration of Δx_1, the main injection event 210 has a duration of Δx_2, and Δx_1 is equal to Δx_2. This embodiment is typically known as split injection. It is noted that the durations, Δx_1 and Δx_2, typically are of different values but are still classified as split injection since the fuel delivery quantities are equal. For example, the magnitudes, i.e., depicted by the Y-axis 206, may differ to compensate for differing durations. For purposes of illustration, however, the durations are shown equal.

[24] Referring back to Fig. 1, the controller 114 may also include means 118 for trimming an injector. The means 118 for trimming an injector preferably refers to the controller 114 being able to adjust the duration of an injection event. More specifically, referring briefly again to Fig. 2, the controller 114 may be able to adjust a duration Δx_1,Δx_2 of at least one of the pilot and main injection events 208,210.

Industrial Applicability

[25] Referring to Fig. 3, a flow diagram illustrating a preferred method of the present invention is shown. The preferred method depicted may be described with respect to an application of the present invention.

[26] In a first decision block 302, it is determined if the engine 102 is operating in a steady load condition. The engine 102 may be operated in a test cell environment, under service conditions, or during normal operation in which the load applied to the engine 102 does not vary. If a steady load condition is not found, the test is abandoned as shown in a first control block 304. It is noted that, although first decision block 302 is shown at one location on the flow diagram, the steady load condition must be maintained throughout the test or the test must be abandoned at any time the load changes.

[27] In a second control block 306, the engine speed governor is modified. For example, in the PI controller 402 of Fig. 2, the proportional gain of the forward PI module 404 may be altered, e.g., reduced, and the integral gain of the forward PI module 404 may be set to zero. This would have the effect of

"loosening", i.e., modifying, the engine speed control device 112 so that some degree of changes in engine speed are allowed. In alternative configurations, the engine speed control device 112 may be temporarily uncoupled for test purposes.

[28] The engine speed is then allowed to settle into a steady state condition and, in a third control block 308, a reference engine speed is determined.

[29] In a fourth control block 310, a first injector 104 for testing is chosen. Typically, the tests will be conducted for all injectors 104 in the engine 102 before the test is terminated.

[30] In a fifth control block 312, the main injection event 210 is cut out. Control then proceeds to a sixth control block 314, in which a change in speed from the reference speed, Δ speed$_1$, is determined. In an alternative embodiment, a change in time it takes to change from the reference speed to a predetermined other speed may be determined.

[31] In a seventh control block 316, the main injection event 210 is maintained in a cut out state and the pilot injection event 208 is also cut out. Then, in an eighth control block 318, a further change in speed from the previous change in speed, Δ speed$_2$, is determined.

[32] In a ninth control block 320, the main and pilot injection events 208,210 for the injector 104 being tested are restored.

[33] In a second decision block 322, it is determined if another injector 104 needs to be tested. If yes, control proceeds to a tenth control block 324, in which the next injector 104 is chosen and the control steps 312-320 are repeated. If no, control proceeds to an eleventh control block 326, in which an average Δ speed is determined from all the previously determined Δ speeds. In a split injection system, i.e., the pilot injection events are equal in fuel delivery to the main injection events, all Δ speeds are used to determine the average Δ speed. If the pilot injection events are not equal in fuel delivery to the main injection events, e.g., the pilot injection events are a smaller percentage of the total

injection duration, then an average Δ speed may be determined for the pilot events and a different Δ speed may be determined for the main events.

[34] In variations of the above steps, control blocks 312-320 may be modified in various ways, such as the main injection event 210 may be turned back on prior to turning off the pilot injection event 208, or the pilot injection event 208 may be turned off first, then the main injection event 210 may be turned off.

[35] In a twelfth control block 328, one or more injection events are trimmed as a function of the average Δ speed. For example, the duration of at least one of the pilot and main injection events 208,210 for each injector 104 may be adjusted, i.e., trimmed. Alternatively, one or more injection events may be modified by varying the timing of the event. The entire process may then be repeated with the new trims, thus making the overall trim process iterative; that is, the process may be repeated until either the injection events are determined to be adequate or until a set number of iterations are performed.

[36] In a thirteenth control block 330, engine speed control is restored and normal operations may resume.

[37] Other aspects can be obtained from a study of the drawings, the disclosure, and the appended claims.